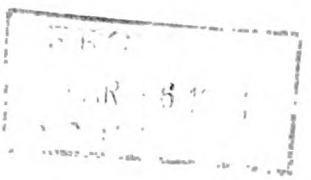
I. C. 6757 JANUARY, 1934

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR



REVIEW OF FINE GRINDING IN ORE CONCENTRATORS

This paper presents the results of work done under a cooperative agreement between the U. S. Bureau of Mines and the Missouri School of Mines and Metallurgy, Rolla, Mo.

BY

ALEXANDER M. GOW, MORRIS GUGGENHEIM, AND WILL H. COGHILL

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

I. C. 6757,
January, 1934

INFORMATION CIRCULAR

UNITED STATES BUREAU OF MINES

REVIEW OF FINE GRINDING IN ORE CONCENTRATORS[1]

By Alexander M. Gow,[2] Morris Guggenheim,[3] and Will H. Coghill[4]

INTRODUCTION

This paper summarizes a survey of fine-grinding practice in ore-concentrating plants throughout the United States, Alaska, Canada, Mexico, and Cuba as reported in the Bureau of Mines Information Circulars on milling methods. The survey covers 49 concentrators, which have a combined capacity of over 160,000 tons per day. In these plants 470 ball, rod, and pebble mills prepare material for flotation, gravity concentration, amalgamation, cyanidation, and air separation. The ores are those of gold, silver, copper, lead, zinc, molybdenum, feldspar, and pyrite. The metallurgy is that of the period 1928–32.

Of these 49 concentrators, 36 are in the United States. They can treat 134,400 tons per day, and they have 326 fine-grinding mills. In the United States there are about 100 active or temporarily idle concentrators, exclusive of the many plants in the Tri-State zinc district, the washeries of the Lake Superior iron ranges and the Florida phosphate area, and small gold and silver concentrators. These 100 plants have an estimated capacity of 290,000 tons per day and employ about 650 ball, rod, and pebble mills. Consequently, since this paper covers about half of the production of this country it may be considered as particularly representative of fine grinding in ore mills in the United States.

It is the aim of this paper to facilitate comparison between the mills of different localities. For this purpose the data have been arranged in tables to which the text should be regarded as supplementary.

Table 1 lists the concentrators and presents general information regarding the fine grinding sections; table 2 shows products and costs; and in table 3 the grinding mills are listed by size. Appended is a bibliography of information circulars listed by key numbers and with the reference names underscored.

This paper represents the result of cooperative work between the Mississippi Valley Experiment Station of the U. S. Bureau of Mines and the Missouri School of Mines and Metallurgy, Rolla, Mo.

GENERAL INFORMATION

Considerable variation in fine-grinding flow sheets and in the many methods of ball-mill operation is shown in this review. Obviously, there is no standardization oven in concentrators in the same district. Contributing to this condition are many factors, including the type of coarse and intermediate crushing machinery, the available fine-grinding equipment, the original design of the concentrators, the tonnage to be treated, the degree of

1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6757."

2 Assistant metallurgist, U.S. Bureau of Mines.

3 Junior metallurgist, U.S. Bureau of Mines.

4 Supervising engineer, ore-dressing section, Metallurgical Division, U.S. Bureau of Mines.

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

fineness necessary for liberation, the grade of the finished product, the general local practice, and the resistance to grinding of the ore.

In a few circulars [United Verde (5), Britannia (19), and Pecos (34)] the relative hardness and toughness of the ore have been indicated, but the industry still is in need of a universally approved method of determining a "grindability factor" so that ores may be compared as to their relative amenability to comminution.

Generated on 2024-09-17 14:39 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills

(Section A)

COPPER ORES

No.	Property	Plant rated tons per day	Type of flow sheet	Grinding mills			Circuit	Speed	
				No.	Kind	Size		R.p.m.	Percent critical
1	2	3	4	5	6	7	8	9	10
1	Hayden	10,500	F	14	Ball	7 feet by 10 feet	Closed	16	55
2	Cananea	2,400	Ar + D and Dr + F	3	Rod	6 feet by 12 feet	Pri. op./cl.	16	48
				4	Ball	8 feet by 28 inches	Sec. closed	16	58
				2	do.	do.	do.	18	64
3	Harmony	200	D	1	Ball	7 feet by 36 inches	Closed	26	86
4	Magma	750	D + conc. + E	3	Ball	6 feet by 4½ feet	Pri. closed	25	78
				3	do.	5 feet by 10 feet	Sec. closed	26	72
5	United Verde	1,500	D + E	1	Ball	8 feet by 12 feet	Pri. closed	18	67
				2	do.	do.	Sec. closed	16	59
6	C. & H. recl.	3,000	Dp	64	Pebble	8 feet by 18 inches	Closed	26	93
7	Nacozari	2,700	Cr + Dr	6	Rod	6 feet by 12 feet	Pri. open	18	55
				6	do.	do.	Sec. closed	18	55
8	C. & H. congl.	2,900	Ap	12	Pebble	8 feet by 72 inches	Open	24	85
9	Hurley	13,000	Cr + D	9	Rod	7 feet by 10 feet	Pri. open	20	66
				18	Ball	7 feet by 10 feet	Sec. closed	20	66
10	Copper Queen	4,000	Cr + D	8	Rod	6 feet by 12 feet	Pri. open	18	55
				8	Ball	6 feet by 12 feet	Sec. closed	18	55
11	Morenci	5,000	F + conc. + E	3	Ball	7 feet by 10 feet	Pri. closed	18	60
				3	do.	8½ feet by feet	do.	14	53
				5	do.	6½ feet by feet	Sec. closed	19	62

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section A - Continued)

COPPER ORES - Continued

No.	Property	Plant rated tons per day	Type of flow sheet	Grinding mills			Circuit	Speed	
				No.	Kind	Size		R.p.m.	Percent critical
1	2	3	4	5	6	7	8	9	10
12	Old Dominion	1,500	B + F, and Dr	4	Ball	6 feet by 50 inches	Pri. open	-	-
				1	do.	do.	Sec. closed	-	-
				1	do.	8 feet by 36 inches	do.	-	-
				1	rod	6 feet by 12 feet	Closed	18	56
13	Arthur and Magma	54,000	B + E, and E + F	13	Ball	7 feet by 10 feet	Pri. open	21	68
				39	do.	do.	Sec. closed	20	66
				18	do.	do.	Pri. closed	21	68
				36	do.	do.	Sec. closed	20	66
14	Verde Central	400	D	2	Ball	8 feet by 36 inches	Closed	15	53
15	Matahambre	1,300	D + E	4	Ball	6 feet by 4½ feet	Pri. closed	25	78
				4	do.	6 feet by 6 feet	Sec. closed	25	76
				1	do.	5 feet by 5 feet	do.	29	80
16	Engels	1,500	C + D	3	Ball	8 feet by 36 inches	Pri. open	20	72
				1	do.	8 feet by 6 feet	Pri. part. cl.	21	78
				2	do.	6 feet by 12 feet	Sec. closed	24	73
				1	do.	6 feet by 10 feet	do.	23	70
				1	do.	8 feet by 36 inches	do.	17	60
17	Walker	1,700	D	3	Ball	7 feet by 5 feet	Closed	24	83
				1	do.	7 feet by 7 feet	do.	24	83
18	Miami	17,000	F' + D + E and E, and F	12	Ball	8 feet by 36 inches	Pri. part. cl.	20	72
				12	do.	do.	Sec. closed	20	72
				6	do.	10½ feet by 8 feet	Tert. closed	13	52
				2	do.	6 feet by 12 feet	Retr. closed	23	70
				1	do.	6 feet by 22 inches	Mid. closed	25	76

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section A - Continued)

COPPER ORES - Continued

No.	Property	Plant rated tons per day	Type of flow sheet	Grinding mills			Circuit	Speed	
				No.	Kind	Size		R.p.m.	Percent critical
1	2	3	4	5	6	7	8	9	10
19	Britannia	6,500	Modified A + E, and C + E	6	Ball	6 feet by 11 feet	Pri. open	24	73
				18	do.	5½ feet by 9 feet	Sec. closed	20	58
				2	do.	7 feet by 10 feet	Conc. closed	-	-
			LEAD AND ZINC ORES						
20	No. Idaho	2,220	Various	1	Ball	8 feet by 36 inches	Low-mid. closed	18	66
	West			1	do.	6 feet by 22 inches	Hi-mid. open	26	79
				2	do.	do.	Hi-mid. closed	25	76
	South			1	Ball	8 feet by 36 inches	Pri. part. cl.	-	-
				1	do.	do.	Sec. closed	-	-
				2	do.	6 feet by 22 inches	-	-	-
	Sweeney			1	Ball	8 feet by 36 inches	Closed	21	74
	Crescent			1	Ball	6 feet by 22 inches	-	26	79
				1	do.	4 feet by 4 feet	-	28	72
	Deadwood			1	Ball	6 feet by 22 inches	Closed	26	79
21	Chief Cons.	165	D	1	Ball	8 feet by 48 inches	Closed	20	72
22	Netta	[2]600	Modified E	1	Ball	6 feet by 10 feet	Closed	20	61
23	White Bird	[2]300	Modified E	1	Ball	6 feet by 36 inches	Closed	24	73
24	Black Hawk	170	D	1	Ball	6 feet by 6 feet	Closed	25	78
25	Mascot	1,900	Cr + A	1	Rod	7 feet by 10 feet	Pri. open	17	55
				1	Ball	5½ feet by 22 inches	Sec. open	23	67

[2]Tons per 10 hours.

Generated on 2024-09-17 14:43 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section A - Continued)

LEAD AND ZINC ORES - Continued

No.	Property	Plant rated tons per day	Type of flow sheet	Grinding mills			Circuit	Speed	
				No.	Kind	Size		R.p.m.	Per-cent crit-ical
1	2	3	4	5	6	7	8	9	10
26	Tybo	320	D	2	Ball	8 feet by 48 inches	Closed	19	68
27	Hughesville	400	Dr	1	Rod	6½ feet by 12 feet	Closed	18	57
28	Midvale	1,000	Dr + E	3	Rod	5 feet by 10 feet	Pri. closed	18	49
				3	Ball	5 feet by 10 feet	Sec. closed	27	75
29	Ruby	250	F	1	Ball	8 feet by 36 inches	Closed	16	58
30	Balmat	500	Dr	1	Rod	6½ feet by 12 feet	Closed	18	55
31	Morning	1,200	D' + D, and E	5	Ball	8 feet by 36 inches	Pr. part. cl.	21	75
				2	do.	do.	Sec. closed	21	75
				2	do.	8 feet by 22 inches	Mid. closed	23	82
32	Page	300	D' + A + E	1	Ball	6 feet by 4 feet	Pri. part. cl.	25	78
				1	do.	6 feet by 16 inches	Sec. open	28	85
				1	do.	8 feet by 36 inches	Tert. closed	22	78
33	Hecla	900	Modified E and D	1	Ball	5 feet by 6 feet	Closed	-	-
				1	do.	6 feet by 22 inches	do.	-	-
				3	do.	8 feet by 36 inches	Retr. closed	21	75
34	Pecos	600	D	2	Ball	7 feet by 5 feet	Closed	22	78
35	Flat River	5,000	Modified Er + conc. + modi-fied Er	6	Rod	6½ feet x 12 feet	Pri. closed	17	54
				1	do.	5 feet by 9 feet	Mid. closed	21	58
36	Potosi	2,400	Dr	4	Rod	7 feet x 12 feet	closed	16	54
				2	do.	5 feet x 12 feet	do.	22	60

Generated on 2024-09-17 14:52 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued
(Section A - Concluded)

No.	Property	Plant rated tons per day	Type of flow sheet	Grinding mills			Circuit	Speed	
				No.	Kind	Size		R.p.m.	Percent critical
1	2	3	4	5	6	7	8	9	10
GOLD ORES									
37	Alaska-Juneau	11,000	D, and (C or D) + D	11	Ball	8 feet by 6 feet	Pri. op. or cl.	22	80
				5	do.	6 feet by 12 feet	Sec. closed	25	80
38	Homestake	2,000	Fr + Bp + Ep	8	Rod	5 feet by 10 feet	Pri. closed	20	55
				2	Pebble	5 feet by 14 feet	Sec. open	-	-
				1	do.	do.	Tert. closed	-	-
				1	do.	6 feet by 72 inches	do.	-	-
39	Spring Hill	150	D	2	Ball	7 feet by 36 inches	Closed	23	76
40	Porcupine	25	D	1	Ball	4½ feet by 16 inches	Closed	31	83
41	Kirkland Lake	150	A + modified E	1	Ball	8 feet by 30 inches	Pri. open	16	58
				1	do.	5½ feet by 16 feet	Sec. closed	28	82
42	Coniaurum	500	Modified E	1	Ball	5 feet by 16 feet	Closed	28	77
MISCELLANEOUS ORES									
43	Minpro	[2]75	Dp	1	Pebble	8 feet by 48 inches	Closed	28	98
				2	do.	8 feet by 36 inches	do.	28	98
				1	do.	4 feet by 16 feet	do.	-	-
44	Questa	50	D	1	Ball	5 feet by 4 feet	Closed	27	75

[2]Tons per 10 hours.

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section B)

COPPER ORES

No.	Property	Grinding media				Pulp, percent solids	Circulating load, percent	Power		Mill closed or followed by
		Pounds	Percent mill volume	Size	Kind			Horsepower of each	All, percent plant total	
		11	12	13	14	15	16	17	18	19
1	Hayden	32,000	32	2 inches	c.s.	80	264	140	30	14 Dorr, 8 by 28 feet.
2	Cananea	44,000	41	3¼ inches by 12 feet	-	-	-	112	18	Dorr, 4 by 12 feet and bowl 6 by 28 by 12feet
		18,000	31	2½ inches	-	68	-	91	31	4 Drag.
		30,000	50	2½ inches	-	68	700	116		2 Dorr, 6 by 23 feet.
3	Harmony	27,000	52	3½ inches	c.i.	72	-	89	50	Dorr, 4½ by 16 feet and flotation.
4	Magma	9,000	25	5 inches	f.s.	62	45	34	12	3 Callow screen and tables.
		18,000	38	2 inches	c.i.	67	100	28	10	3 Esperanza, 2½ by 38 feet.
5	United Verde	66,000	40	3¼ inches	c.i.	81	400	[1]300	60	4 Dorr, 8 by 30 feet.
		66,000	40	2½ inches	do.	78	100	[1]268		Bowl 8 by 33 by 22 feet.
6	C. & H. recl.	-	-	-	peb.	-	-	-	-	Tables.
7	Nacozari	36,000	30	3 inches by 12 feet	-	78	0	131	32	3 Bowl, 6 by 20 by 13 feet.
		36,000	30	2½ inches by 12 feet	-	73	170	124	31	6 Dorr, 6 by 23 feet.
8	C. & H. congl.	-	-	4 inches	peb.	25	-	-	-	-
9	Hurley	42,000	34	3 inches by 9 feet		65	0	155	15	9 Bowl, 8 by 27 by 15 feet.
		36,000	35	2 inches	c.i.	70	-	162	31	18 Dorr, 8 by 27 feet.
10	Copper Queen	38,000	31	3 inches by 12 feet		74	0	141	35	8 Bowl, 6 by 28 by 15 feet.
		-	-	3½ inches	c.s.	75	-	121	30	8 Dorr, 6 by 23 feet.

[1]Estimated from other data as explained in the text.

Generated on 2024-09-17 14:39 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section B - Continued)

COPPER ORES - Continued

No.	Property	Grinding media				Pulp, percent solids	Circulating load, percent	Power		Mill closed or followed by
		Pounds	Percent mill volume	Size	Kind			Horsepower of each	All, percent plant total	
		11	12	13	14	15	16	17	18	19
11	Morenci	40,000	39	3 inches	c.i.	-	125	-		3 Dorr, 8 by 26 feet.
		66,000	36	3 inches	c.i.	-	125	-	53	3 do.
		36,000	30	2 inches	c.i.	-	-	-		5 Bowl, 8 by 31 by 18 feet
12	Old Dominion	13,000	30	2½ inches	c.i.	50	0	80		Bowl, 8 by 23 by 18 feet.
		-	-	2 inches	c.i.	60	360	[1]70	56	Dorr, 6 by 20 feet and flotation.
		-	-	2 inches	c.i.	70	360	[1]80		Dorr, 8 by 20 feet and flotation.
		41,000	34	3 inches by 12 feet		70	300	130		Dorr, 8 by 27 feet.
13	Arthur and Magna	42,000	41	3-3/8 inches	c.i.	-	0	-		
		42,000	41	2 inches	c.i.	-	-	-	45	39 Drag, 12 by 16 feet.
		42,000	41	2-3/8 inches	c.i.	-	-	-		18 Drag, 8 by 14 feet.
		42,000	41	2 inches	c.i.	-	-	-		36 Drag, 6 by 18 feet and 36, 8 feet by 18 feet.
14	Verde Central	-	-	3 inches	c.i.	-	-	-	53	2 Dorr, 6 by 26 feet.
15	Matahambre	9,000	25	4½ inches	f.s.	83	110	-	-	2 Trommel, 4 by 13 feet.
		9,000	20	3 inches	f.s.	80	150	-	-	4 Dorr, 8 by 18 feet.
		7,500	34	3 inches	f.s.	80	-	-	-	Dorr, 3 by 18 feet.
16	Engels	24,000	36	5 inches	c.s.	80	0	147		3 Dorr, 6 by 24 feet.
		25,000	28	5 inches	c.s.	83	33	268		1 do.
		28,000	32	2½ inches	c.s.	76	315	160	57	2 do.
		15,000	20	2½ inches	c.s.	76	340	129		1 do.
		24,000	36	2½ inches	c.s.	76	340	100		1 do.

[1]Estimated from other data as explained in the text.

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section B - Continued)

No.	Property	Grinding media				Pulp, percent solids	Circulating load, percent	Power		Mill closed or followed by
		Pounds	Percent mill volume	Size	Kind			Horsepower of each	All, percent plant total	
		11	12	13	14	15	16	17	18	19
COPPER ORES - Continued										
17	Walker	18,000	30	4 inches	f.s.	78	145	[1]157	59	3 Dorr, 6 by 18 feet.
		26,000	31	4 inches	f.s.	78	145	[1]220		Dorr, 6 by 23 feet.
18	Miami	-	-	-	-	-	-	-		12 Dorr, 6 by 19 feet.
		-	-	-	-	-	-	-		12 do.
		-	-	-	-	-	-	-	52	Bowl, 20 by 42 by 28 feet.
		-	-	-	-	-	-	-		Bowl, 6 by 23 by 15 feet.
		-	-	-	-	-	-	-		Bowl, 6 by 23 by 15 feet.
19	Britannia	14,000	17	3½ inches	f.s.	70	0	-		-
		14,000	26	3½ inches	f.s.	70	-	-	59	18 Dorr, 3 by 20 feet.
		-	-	1½ inches	f.s.	-	-	-		Drag and bowl.
LEAD AND ZINC ORES										
20	No. Idaho	-	-	3 inches	c.i.	70	334	125	-	Dorr, 6 feet.
	West	-	-	3 inches	c.i.	51	0	-	-	-
		-	-	2½ inches	c.i.	76	860	-	-	Dorr, 6 feet.
	South	-	-	3 inches	c.i.	53	100	158	-	Dorr, 6 feet.
		-	-	3 inches	c.i.	-	400	125	-	do.
		-	-	3 inches	c.i.	74	-	45	-	-
	Sweeney	-	-	3 inches	c.i.	-	266	134	-	Esperanza, 5 by 18 feet.
	Crescent	-	-	3 inches	c.i.	-	300	48	-	Dorr, 2¼ feet.
		-	-	2 inches	c.i.	-	300	-	-	
	Deadwood	-	-	3 inches	c.i.	-	500	45	-	Dorr, 4½ feet.
21	Chief Cons.	-	-	5 inches	f.s.	75	335	180	38	Dorr, 6 by 20 feet.
22	Netta	30,000	-	3 inches	f.s.	-	-	-	-	Drag and tables.
23	White Bird	16,000	45	3 inches	f.s.	70	-	-	16	Screen and tables.
24	Black Hawk	13,000	27	4 inches	f.s.	72	300	-	-	Dorr, 6 by 18 feet.

[1]Estimated from other data as explained in the text.

Generated on 2024-09-17 14:43 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Continued

(Section B - Continued)

LEAD AND ZINC ORES - Continued

No.	Property	Grinding media				Pulp, percent solids	Circulating load, percent	Power		Mill closed or followed by
		Pounds	Percent mill volume	Size	Kind			Horsepower of each	All, percent plant total	
		11	12	13	14	15	16	17	18	19
25	Mascot	55,000	43	3 inches by 10 feet	-	-	0	146	-	Dorr, 8 by 25 feet.
		40,000	31	2½ inches	-	-	0	158	-	-
26	Tybo	36,000	46	3 inches	c.s.	76	400	139	65	2 Dorr, 6 by 25 feet.
27	Hughesville	-	-	-	-	-	300	195	36	Dorr, 8 by 30 feet.
28	Midvale	20,000	34	2 inches by 10 feet		78	57	[1]62	35	3 Akins, 54 inches
		15,000	31	2½ inches	c.i.	78	-	[1]100		3 Akins, 54 inches.
29	Ruby	32,000	48	3 inches	c.i.	-	-	135	35	Drag.
30	Balmat	-	-	2½ inches by 12 feet	-	-	207	181	21	Dorr, 8 by 30 feet.
31	Morning	32,000	48	4 inches	c.i.	-	-	-		5 Esperanza, 8 by 21 feet.
		26,000	39	3 inches	c.i.	-	-	-	46	2 do.
		-	-	1½ inches	f.s.	-	-	-		Thickener, 18 feet.
32	Page	-	-	-	-	-	-	-	-	Dorr 4 feet.
		-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	Esperanza.
33	Hecla	-	-	-	-	-	-	-	-	Drag, 6 by 14 feet.
		-	-	-	-	-	-	-	-	
		-	-	-	-	-	300	-	-	3 Dorr, 5 by 18 feet.
34	Pecos	-	-	4½ inches	f.s.	-	400	151	36	2 Dorr, 6 by 23 feet.
35	Flat River	55,000	45	2 inches by 12		66	-	190	24	Screens and tables.
		28,000	50	2 inches by 9 feet		66	-	95		Flotation.

[1]Estimated from other data as explained in the text.

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 1.- Operating data of fine grinding mills - Concluded

(Section B - Concluded)

LEAD AND ZINC ORES - Concluded

No.	Property	Grinding media				Pulp, percent solids	Circulating load, percent	Power		Mill closed or followed by
		Pounds	Percent mill volume	Size	Kind			Horsepower of each	All, percent plant total	
		11	12	13	14	15	16	17	18	19
36	Potosi	-	-	3 inches by 12 feet	-	-	-	[1]110	40	Dorr.
		-	-	do.	-	-	-	[1]47		do.
	GOLD ORES									
37	Alaska-Juneau	20,000	22	6 inches	f.s.	40	140	187	-	Trunnion trommel
		20,000	21	5 inches	c.s.	40	90	113	-	do.
38	Homestake	23,500	40	3 inches by 10 feet	-	-	-	76	-	8 Dorr, 4 by 22 feet.
		-	-	2½ inches	peb.	74	0	-	-	
		-	-	2½ inches	peb.	-	-	-	-	Dorr, 4 by 22 feet.
		-	-	2½ inches	peb.	-	-	-	-	
39	Spring Hill	-	-	4 inches	c.i.	55	500	-	56	2 Dorr, 4 by 14 feet.
40	Porcupine	4,000	42	4 inches	f.s.	34	125	-	44	Amalgamation and Dorr, 4 by 15 feet.
41	Kirkland Lake	30,000	50	5 inches	f.s.	75	0	-	70	Dorr, 6 by 20 feet and bowl.
		15,000	16	1½ inches	f.s.	73	115	-		
42	Coniaurum	-	-	2 inches	f.s.	70	-	-	-	Dorr, 6 by 30 feet and bowl.
	MISCELLANEOUS ORES									
43	Minpro	12,800	42	4 inches	peb.	-	-	-		Air separator and screens.
		11,600	45	4 inches	peb.	-	-	-	87	
		6,000	33	2 inches	peb.	-	-	-		
44	Questa	4,200	22	4 inches	f.s.	80	280	43	43	Dorr, 3 by 18 feet.

[1]Estimated from other data as explained in the text.

Generated on 2024-09-17 14:58 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills

(Section A)

COPPER ORES

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrated		Distribution of grinding costs, percent			Iron wear per ton milled, pounds	
									Total	For grinding	Labor	Supplies	Power	Balls or rods	Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
				Percent	Mesh	Percent	Mesh								
1	Hayden (1928)	Ball	241	98	10	97	65	Milk of lime	$0.399	$0.078	19	35	46	1.00	0.07
				10	200	62	200								
2	Cananea	Pri. rod	102	95	1 inch	99	10	Dry lime		.062	12	40	48	.60	.04
	(6 mo. 1929)			9	200	36	200								
									.617						
		Sec. ball	-	98	10	98	48	-		.116	3	44	53	1.36	14
				3	200	54	200			.178					
3	Harmony	Ball	8		½ inch	-	70	Collector	.651	.284	21	54	25	3.1	.5
	(3½ mo. 1929)					65	200								
4	Magna	Pri. ball	33	98	1 inch	97	14	Dry lime		.139	21	63	16	1.25	.27
	(6 mo. 1929)			3	200	54	200								
									.934						
		Sec. ball	-	98	14	99	48	Aerofloat		.10	24	57	19	1.75	.19
				5	200	57	200			.239					
5	United Verde	Pri. ball	66	97	3	98	35	Milk of lime							
	(Sept. 1929)			12	200	56	200	CaCN							
									.736	.164	16	39	45	2.03	.22
		Sec. ball	-			94	65	-							
						74	200								
6	C. & H. recl. (1929)	Pebble	128	-		-		-	.495	.172	7	39	54	-	-
7	Nacozari	Pri. rod	108	95	1½ inch	99	8	Dry lime		.106	10	44	56	.99	.24
	(1928-1929)			7	200	28	200								
									.513						
		Sec. rod	-	98	8	94	48	-		.117	11	50	39	1.19	.39
				3	200	58	200			.223					

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills - Continued

(Section A - Continued)

COPPER ORES - Continued

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrates		Distribution of grinding costs, percent			Iron wear per ton milled, pounds	
									Total	For grinding	Labor	Supplies	Power	Balls or rods	Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
				Percent	Mesh	Percent	Mesh								
8	C. & H. congl. (1929)	Pebble	110	-		-		-	.533	.081	8	31	61	5.0*	
	Hurley	Pri. rod	560	94	4	99	10		-	-	-	-	-	.40	-
				15	200	33	200	Milk of lime							
		Sec. ball	-	99	10	97	65		-	-	-	-	-	1.46	-
				5	200	57	200	Milk of lime							
10	Copper Queen	Pri. rod	178	99	1 1/2 inch	99	20			.111	17	46	37	1.34	.04
	(1929)			13	200	45	200	Dry lime							
									.493						
		Sec. ball	-	98	20	99	65	-		.083	14	44	42	1.41	.08
				13	200	74	200			.194					
11	Morenci	Pri. ball	216	33	48	94	48	Milk of lime		.074	-	-	-	1.19	.21
	(April 1930)			19	200	53	200								
									.519						
		Sec. ball	-		-	98	65	Potassium		.051	-	-	-	.69	.03
						72	200	ethyl xanthate		.125					
12	Old Dominion	Pri. ball	52	95	3	75	35	Milk of lime		.094	-	-	-	1.32	.22
				9	200	36	200								
									.699						
		Sec. ball	-	70	35	89	48	Milk of lime		.093	-	-	-	1.28	.08
				8	200	42	200	Oils		.187					
		Rod	11	97	3/4 inch	94	48	Milk of lime							
				11	200	52	200	Oils							

* Pebbles.

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills - Continued

(Section A - Continued)

COPPER ORES - Concluded

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrated		Distribution of grinding costs, percent			Iron wear per ton milled, pounds	
									Total	For grinding	Labor	Supplies	Power	Balls or rods	Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
				Percent	Mesh	Percent	Mesh								
13	Arthur and Magna	Pri. ball	-	99	10	-		-							
	(1 mo., 1929)			26	200										
									.302	.092	12	33	55	-	-
		Sec. ball	-	-		90	100	-							
						68	200								
14	Verde Central	Ball	17	-	1/4 inch	96	48	Dry lime	1.26	.37	21	33	46	-	-
	(June 1929 to Aug. 1930)														
15	Matahambre (1930)	Pri. ball	54	98	4	99	4	Dry lime		.127	-	-	-	-	-
				3	200	29	200	NaCN							
									.747						
		Sec. ball	-	98	14	99	35	Pine oil		.136	-	-	-	.69	.54
				25	200	44	200			.263					
16	Engels (1929)	Pri. ball	72	98	1 inch	98	8	Dry lime		.153	17	48	35	1.08	.21
				4	200	30	200	Fuel oil							
									.652						
		Sec. ball	-	97	3	99	48	-		.094	22	41	37	.72	.10
				12	200	65	200			.247					
17	Walker	Ball	72	95	1 inch	98	30	Slaked lime	-	-	-	-	-	2.07	.56
				1	200	44	200	Pine oil							
18	Miami (1930)	Ball	-	-	3	97	48	-	.297	.091	18	46	36	-	-
19	Britannia	Pri. ball	-	96	4	-		Milk of lime							
	(July 1931)								.177	.046	23	45	32	2.5	.18
		Sec. ball	-	-		97	28	-							
						40	200								

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills - Continued

(Section A - Continued)

LEAD AND ZINC ORES

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrated		Distribution of grinding costs, percent			Iron wear per ton milled, pounds	
									Total	For grinding	Labor	Supplies	Power	Balls or rods	Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
				Percent	Mesh	Percent	Mesh								
20	N. Idaho (1929)	Ball	-	98	3	99	100	Cresylic, NaCN	1.270	.292	7	61	32	3.0	-
								Aero. $ZnSO_4$							
21	Chief Cons. (1929)	Ball	7	93	1 inch	98	65	H_2SO_4	3.217	.455	17	40	43	3.42	.71
				2	200	73	200								
24	Black Hawk	Ball	7	95	1/4 inch	93	100	Soda ash	1.55	.355	-	-	-	1.5	-
	(2 mo., 1929)			6	200	75	200	Thio.							
25	Mascot	Pri. rod	29		-		-	-	-	-	-	-	-	-	-
		Sec. ball	-		-		-	-		.053	-	-	-	-	-
26	Tybo (March 1930)	Ball	14		1 1/4 inch	95	65	Soda ash	1.282	.445	12	41	47	2.7	-
						69	200	NaCN, $ZnSO_4$							
27	Hughesville	Rod	13	99	1 inch	99	48	-	-	-	-	-	-	1.99	-
				2	200	48	200								
28	Midvale	Pri. rod	45	94	1/2 inch	99	28	-		-	-	-	-	1.20	.21
				13	200	40	200								
									-						
		Sec. ball	-	99	28	98	48	-		-	-	-	-	1.10	.21
				11	200	60	200								
29	Ruby	Ball	-		4	98	40	Soda ash, NaCN	2.202	.252	9	41	50	3.19	-
	(Oct. 1929 to April 1930)					30	200	Thio., $ZnSO_4$							
30	Balmat	Rod	24	92	3/4 inch	94	35	Thio.	-	-	-	-	-	2.2	-
				5	100	30	200								
31	Morning (1929)	Pri. ball	-		-		-	-							
		Sec. ball	-		-	99	65	-	1.012	.193	12	45	43	2.19	.4
						81	200								

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:41 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills - Continued

(Section A - Continued)

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrated		Distribution of grinding costs, percent			Iron wear per ton milled, pounds	
				Percent	Mesh	Percent	Mesh		Total	For grinding	Labor	Supplies	Power	Balls or rods	Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
LEAD AND ZINC ORES - Continued															
32	Page (1930)	Pri ball	-		1 inch	-		-							
				10	100										
		Sec. ball	-		-	-		-	.905	.411	17	51	32	-	-
		Tert. ball	-		-	99	48	-							
						72	200								
34	Pecos (1930)	Ball	22	99	1 1/2 inch	98	65	-	1.190	272	18	57	25	1.8	.3
				7	200	81	200								
35	Flat River	Pri. rod	105	99	6	99	20	-							
									-	-	-	-	-	-	-
		Mid rod	-	97	10	98	65	-							
				11	200	82	200								
36	Potosi (July 1932)	Rod	96	95	1/2 inch	97	35	Cresylic	.504	.157	6	31	63	.54	-
				4	200	48	200	NaCN							
GOLD ORES															
37	Alaska-Juneau (1928)	Pri. ball	165	98	2 1/2 inch	96	10	-						.93	.25
				5	7	27	200								
									.326	.16	-	-	-		
		Sec. ball	-	92	3/4 inch	96	10	-						1.35	1.01
				9	14	30	150								
38	Homestake (1929)	Pri. rod	66	57	10	89	50	-		.084	22	55	23	1.30	.36
				3	200	49	200								
		Sec. peb.	-	97	30	-		-	.503						
				2	200										
		Tert peb.	-		-	95	50	-		.014	47	26	27	-	-
						40	200			.098					

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Generated on 2024-09-17 14:39 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Table 2.- Products, reagents in mill feed, and costs of fine grinding mills Concluded

(Section A - Concluded)

No.	Property and year	Circuit	New feed per hour, tons	Skeleton-size analyses of Feed		Skeleton-size analyses of Finished product		Reagents added in mill	Cost per ton concentrated: Total	Cost per ton concentrated: For grinding	Distribution of grinding costs, percent: Labor	Distribution of grinding costs, percent: Supplies	Distribution of grinding costs, percent: Power	Iron wear per ton milled, pounds: Balls or rods	Iron wear per ton milled, pounds: Liners
1	2	3	4	5		6		7	8	9	10	11	12	13	14
				Percent	Mesh	Percent	Mesh								
	GOLD ORES - Continued														
39	Spring Hill	Ball	8	93	1/2 inch	96	80	Pine oil	1.007	.290	35	25	40	1.3	-
	(July 1929 to April 1930)			6	100	60	200	K-xan. Aero.							
40	Porcupine	Ball	1	75	1/2 inch	65	200	-	1.851	.771	56	21	23	1.5	-
41	Kirkland Lake	Pri. ball	-	69	1 inch	98	10	Lime						1.96	.24
	(1930)			2	100	28	200								
		Sec. ball	-		-	95	300	-	1.389	.642	23	37	40		
42	Coniaurum	Ball	-		-	60	200	KCN	.939	.202	-	-	-	2.5	.26
														1.8	-
	MISCELLANEOUS ORES														
43	Minpro (1929)	Pebble	-	-		-		-	1.45	.74	-	-	-	-	-
44	Questa	Ball	2	99	1 1/2 inch	99	100	Pine oil	2.69	-	-	-	-	-	-
	(10 mo., 1930)														

Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 3.- Index of grinding mills

Size Diameter and length	Number in use	Location and reference number
Ball Mills:		
10½ by 8 feet	6	Miami (18)
8½ by 12 feet	3	Morenci (11)
8 by 12 feet	3	United Verde (5)
8 by 6 feet	12	Alaska Juneau (37), Engels (16)
8 feet by 48 inches	3	Chief Cons. (21), Tybo (26)
8 feet by 36 inches	47	Old Dominion (12), Verde Central (14), Engels (16), Miami (18), No. Idaho (20), Ruby (29), Morning (31), Page (32), and Hecla (33)
8 feet by 30 inches	1	Kirkland Lake (41)
8 feet by 28 inches	6	Cananea (2)
8 feet by 22 inches	2	Morning (31)
7 by 10 feet	143	Hayden (1), Hurley (9), Morenci (11), Arthur and Magna (13), Britannia (19)
7 by 7 feet	1	Walker (17)
7 by 5 feet	5	Walker (17), Pecos (34)
7 feet by 36 inches	3	Harmony (3), Spring Hill (39)
6½ by 12 feet	5	Morenci (11)
6 by 12 feet	17	Alaska Juneau (37), Copper Queen (10), Engels (16), Miami (18)
6 by 11 feet	6	Britannia (19)
6 by 10 feet	2	Engels (16), Netta (22)
6 by 6 feet	5	Matahambre (15), Black Hawk (24)
6 by 4½ feet	7	Magma (4), Matahambre (15)
6 feet by 50 inches	5	Old Dominion (12)
6 by 4 feet	1	Page (32)
6 feet by 36 inches	1	White Bird (23)
6 feet by 22 inches	9	Miami (18), No. Idaho (20), Hecla (33)
6 feet by 16 inches	1	Page (32)
5½ by 22 feet	1	Mascot (25)
5½ by 16 feet	1	Kirkland Lake (41)
5½ by 9 feet	18	Britannia (19)
5 by 16 feet	1	Coniaurum (42)
5 by 10 feet	6	Magma (4), Midvale (28)
5 by 6 feet	1	Hecla (33)
5 by 5 feet	1	Matahambre (15)
5 by 4 feet	1	Questa (44)
4½ feet by 16 inches	1	Porcupine (40)
4 by 4 feet	1	No. Idaho (20)
Rod Mills:		
7 by 12 feet	4	Potosi (36)
7 by 10 feet	10	Hurley (9), Mascot (25)
6½ by 12 feet	8	Hughesville (27), Balmat (30), Flat River (35)
6 by 12 feet	24	Cananea (2), Nacozari (7), Copper Queen (10), Old Dominion (12)

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Table 3.- Index of grinding mills - Continued

Size Diameter and length	Number in use	Location and reference number
Rod Mills (Continued:		
5 by 12 feet	2	Potosi (36)
5 by 10 feet	11	Midvale (28), Homestake (38)
5 by 9 feet	1	Flat River (35)
Pebble Mills:		
8 feet by 72 inches	12	C. & H. congl. (8)
8 feet by 48 inches	1	Minpro (43)
8 feet by 36 inches	2	Minpro (43)
8 feet by 18 inches	64	C. & H. recl. (6)
6 feet by 72 inches	1	Homestake (38)
5 by 14 feet	3	Homestake (38)
4 by 16 feet	1	Minpro (43)
Total	470	

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

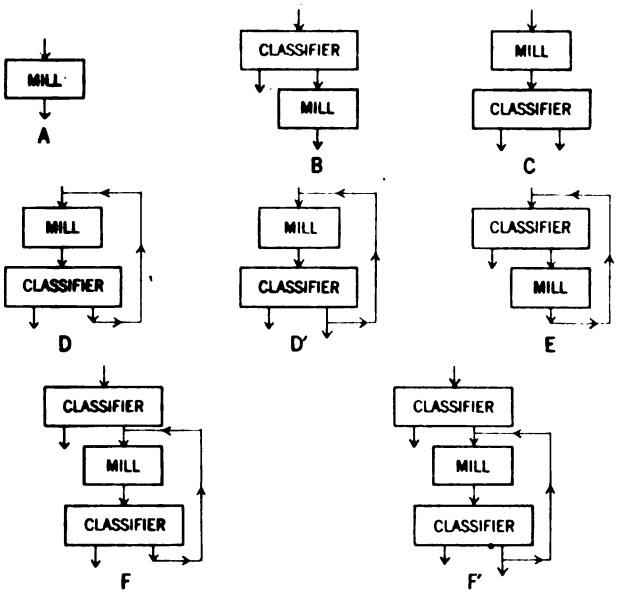


Figure 1.—Types of fine-grinding flow sheets.

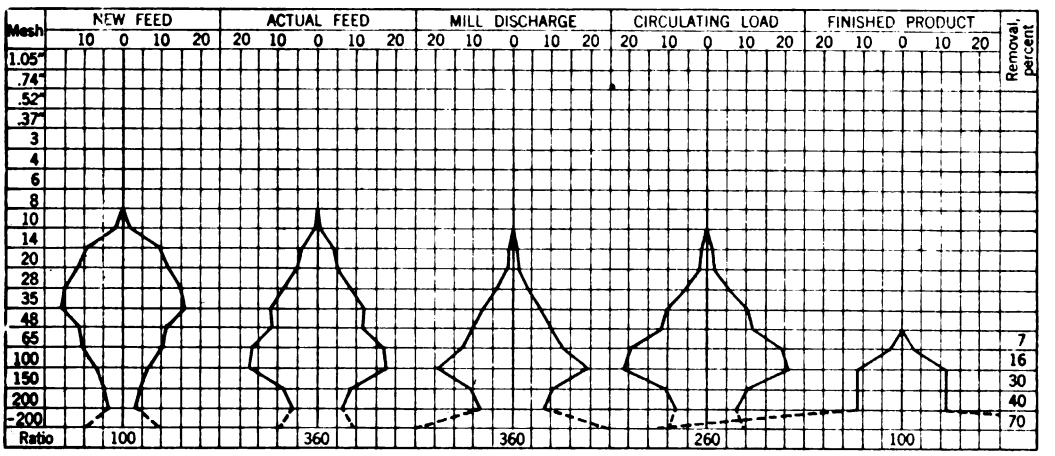


Figure 2.—Sizing diagrams of products of ball mill at Hayden (1).

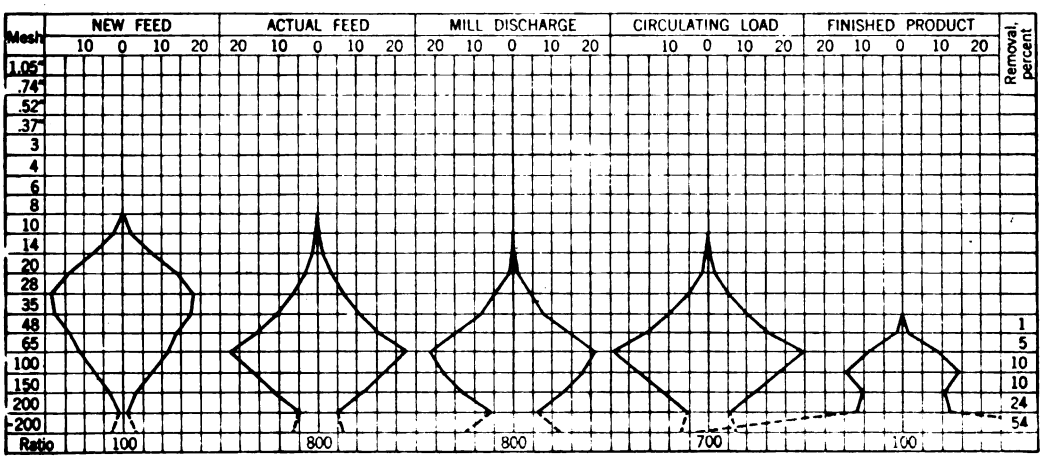


Figure 3.—Sizing diagrams of products of secondary ball mill at Cananea (2).

Generated on 2024-09-17 14:41 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

FLOW SHEETS

Ball, rod, or pebble mills are used either singly or in combinations with classifiers and with other mills. The simplest flow sheet is one in which the ore is ground sufficiently fine in one pass through a single machine. However, while certain particles are being ground to the required size in this open-circuit operation, others are being ground too fine; consequently, when other factors permit, better practice is to grind the ore in stages, removing the finished material intermittently from that which requires additional grinding. This additional grinding is accomplished by returning the unfinished sand either to the same mill (closed circuit) or to a secondary mill. In practice, flow sheets vary from simple open circuits to combinations of several closed-circuited mills in series. The separation of finished material from that in need of more grinding may be accomplished by mechanical classifiers, cones, screens, trommels, tables or other concentrating machinery, or air separators. To simplify the analyses of the flow sheets the following schematic combinations will be adopted (see fig. 1). By "mill" is meant ball mill, rod mill, or pebble mill, and by "classifier" is meant any of the machines used to separate the finished from the unfinished material in the grinding circuit.

Type A - Simple open-circuit mill.

Type B - Open circuit with classifier preceding mill which receives classifier oversize.

Type C - Open circuit with classifier following mill.

Type D - Simple closed circuit, with mill discharge feeding classifier and classifier oversize returning to mill.

Type D'- Simple partly closed circuit, like type D except only part of the classifier oversize returns to mill.

Type E - Inverted closed circuit, with classifier preceding mill which receives classifier oversize and returns mill discharge to the classifier.

Type F - Classified simple closed circuit, in which the mill receives classifier oversize as in type E, but discharges into a second classifier which is in simple closed circuit with the mill.

Type F'- Classified simple partly closed circuit, like type F except that only part of the oversize from the second classifier is returned to the ball mill.

In addition to these types, there are a few which, because of similarity, will be designated as modifications of the above general types. Subscripts r and p indicate that the mills are rod or pebble mills rather than ball mills. The types of flow sheets in the several fine-grinding sections are given in table 1, column 4.

OPERATION

Operating conditions which are discussed by the authors of the circulars are the speed of the mill; the amount, size, and kind of grinding media; the pulp density; the amount of circulating load when the circuit is closed; the type of lining; the size of the discharge opening; and the type and amount of the feed. Very often the conditions which require the most power result in the most grinding, but capacity alone is not always desirable. Ores may be overground with resulting losses in subsequent treatment, and power is often such an expensive item that it should be held at a minimum. Ball-mill operation should be considered with respect to local conditions, and consequently it is impossible to choose arbitrarily the conditions under which a ball mill should be operated for best results. Exigency may demand departure from a practice known to be scientifically sound.

Generated on 2024-09-17 14:42 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Speed

To compare the speed of mills of different diameters, the speed as given in revolutions per minute has been translated into percent of the theoretical critical speed.[5] This value for ball mills ranges from 53 percent [Morenci (11)] to 86 percent [Harmony (3)]; for rod mills it lies between 48 percent [Cananea (2)] and 66 percent [Hurley (9)]; and for pebble mills it ranges from 85 percent [C. & H. congl. (8)] to 98 percent [Minpro (43)]. See columns 9 and 10 of table 1. Slow speeds are sometimes used in the interest of economy [Kirkland Lake (41)] when additional grinding capacity is not needed, but in other instances [Harmony (3)] there cannot be the slightest decrease lest the grinding capacity drop.

Generally, no provision is made for varying the speed of a mill; and consequently variations in grinding are obtained by changing other operating conditions.

Grinding Media

Amount

Ordinarily, the amount of grinding media is known accurately only when the mill is started with a fresh charge or when an old charge is dumped and weighed. The loss due to wear is made up by periodic additions of balls, rods, or pebbles, at a rate which attempts to maintain the original volume. Figures on ball and rod wear will be found in table 2, column 13.

In table 1, column 12, the amount of grinding media is expressed in estimated percentages of the mill volume.[6] Very seldom do mills operate with charges over 55 percent. Mill volumes as low as 17 percent [Kirkland Lake (41)] are reported, while in other mills [Magma (4)] the ball volume is increased only when additional capacity is required.

Comparative tests at Cananea (2) show that an increase in ball load from 9 to 15 tons (31 to 52 percent of mill volume) gave an increase of 67 percent in the minus 48-mesh material produced, and an increase in power of only 27 percent.

Size

The size of the grinding media added is established by the size of the coarsest particles in the feed. At Alaska Juneau (37) where 2½-inch material is present in the feed, balls as large as 6 inches in diameter are used. When grinding is done in several steps, large balls are used in the primary mills, and, generally, smaller ones in the following mills. For regrinding, balls as small as 1½-inch maximum are employed [Britannia (19); Morning (31)]. The average size of make-up balls is 2 to 4 inches. The tendency is to use balls of smaller diameter than those formerly used [Hayden (1), Harmony (3), Hurley (9)]; but at Magma (4) when the ball charge is unusually light, large balls are necessary to maintain tonnage.

Rod diameters, in general, are chosen according to the size of the feed [Nacozari (7)]. The tendency is toward a smaller diameter of rods [Flat River (35)] to avoid breakage which is attributed to large rods.

---

5 The critical speed is given by the formula: 54.19 divided by the square root of inside radius in feet. The inside diameter has been taken from trade catalogs, where possible, and otherwise is assumed to be 6 inches less than the nominal dimension. No correction for ball size has been made. The speed of conical mills is figured on the diameter of the cylindrical portion.

6 The inside diameters of the various mills are estimated as explained under "speed"; the lengths from manufacturers' data, or are assumed to be nominal.

Generated on 2024-09-17 14:44 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Pebbles, because of their lesser density are larger than balls which might be used in their stead. Flint pebbles range in maximum size from 2½ inches [Homestake (38)] to 4 inches [C. & H. (6) and (8), Minpro (43)].

Kind

Grinding balls are either cast or forged. Of the mills listed, 15 use cast balls, 12 use forged balls, and 4 use both. Forged steel balls have the longest life, but the cheapness of cast-iron or cast-semisteel balls often makes their use more economical [Harmony (3), Verde Central (14), Engels (16), and Midvale (28)].

Balls have replaced pebbles in several grinding circuits [Morenci (11), Old Dominion (12), Miami (18), Britannia (19), Hecla (33), and Kirkland Lake (41)], but in some instances where pebbles can be obtained at low cost, they compete successfully with balls [C. & H. (6) and (8)]. In certain installations, such as those for the grinding of feldspar [Minpro (43)], iron cannot be used because of contamination, and pebbles, together with silex or other nonmetallic lining, must be employed.

Rods are of high-carbon steel and are hot-sawed and machine-straightened. The analyses of rods [Cananea (2), Nacozari (7), Copper Queen (10), Homestake (38), Balmat (30), Flat River (35)] fall within the following limits: C, 0.6 to 1.0 percent; Mn, 0.5 to 0.8 percent; Cr, 0.2 to 0.5 percent; Si, 0.15 to 0.25 percent; P, 0.02 to 0.04 percent; and S, 0.03 to 0.05 percent.

No record is made of periodic inspections of the ball or rod charges.

Pulp Density

Pulp densities in ball mills vary from 34 percent solids [Porcupine (40)] to 83 percent solids [Matahambre (15)]. In most instances, the product of the fine-grinding circuit is classifier overflow which goes direct to flotation, but in a few mills [C. & H. (6) and (8), Arthur and Magna (13), Netta (22), White Bird (23), and Float River (35)], thickeners are ahead of flotation and the pulp density of the finished product need not be maintained at flotation density. At Harmony (3) a thick pulp, 68 to 76 percent solids, is maintained to reduce liner and ball wear and to increase capacity and the uniformity of the product; to facilitate control, a density indicator is kept in the discharge pulp. At Alaska Juneau (37) a thin pulp, 40 percent solids, is used to carry the ore through the mill rapidly, thus avoiding overgrinding.

Circulating Load

As may be seen from the tabulation of type of flow sheets in table 1, most of the plants do fine grinding in closed circuits. With the exception of Mascot (25) in which even the secondary ball mill is in open circuit, all secondary circuits are closed. In some cases the circulating load builds up to 400 or 500 percent [United Verde (5), N. Idaho (20), Tybo (26), Pecos (34), and Spring Hill (39)]. At Cananea (2) the circulating load was found to be 700 percent by a calculation similar to the one described in the Copper Queen (10) report; and in one circuit at the West concentrator of the N. Idaho mills (20) it reaches 860 percent.

The building up of sulphides in the classifiers in closed circuit with mills is noted in several plants [Cananea (2), Nacozari (7), Old Dominion (12), and Balmat (30)], and in one plant [Copper Queen (10)] the amount of circulating load fluctuates with the amount of sulphide in the ore.

Generated on 2024-09-17 14:41 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

At Alaska Juneau (37) in the primary and secondary circuits, and in the primary circuit of Matahambre (15), the circulating load is trommel oversize. In the primary circuits at Magma (4) and Flat River (35), and in the White Bird (23) circuit the circulating load is vibrating-screen oversize and table return. At Minpro (43) screens and air separators are used. At the remaining plants mechanical classifiers of the rake, drag, or screw type make a return sand which constitutes most of the circulating load, although flotation and table middlings are sometimes returned for regrinding.

Lining

The majority of the mills use cast iron or steel liners. however, sections of rail set in concrete are used at some plants, and rubber and stone linings are found occasionally. The C. & H. congl. (8) mills are lined with old steel rails, 60 pounds or heavier, imbedded in neat cement. At Hurley (9), 3½-inch lengths of rails are used in the side liners with cast iron end liners. The Arthur and Magna (13) mills have 4-inch lengths of 90-pound rail laid on end against the shell in concrete; and at Britannia (19) the lining is made of 7-inch sections of rail set on end in high-strength concrete. The rail sections in the last instance are hardened by heating and quenching in cold water before being cemented into the mill. The Britannia mills were designed originally as pebble mills, and to adapt them to ball loads an inner lining of 2-inch wooden lagging was placed between the shell and the rail-and-concrete lining.

At Cananea (2) a wood inner lining of 1½ inches is placed between the shell and the liner castings; and at Old Dominion (12) the inside diameter has been reduced by inserting 10-inch timbers under the cast-iron liners. The Old Dominion mills which were originally 8-foot by 36-inch conical mills now measure 6 feet by 50 inches. A 7-by 10-foot mill at Engels (16) was reduced with 6-inch timbers and cast-iron liners to a 6- by 10-foot size. At this concentrator, mills are stopped every 2 weeks, the liners are inspected, and thin liners are replaced. In spite of this precaution, however, the shell becomes worn by pulp flowing between the ends of the liner rows. Some experimental work has been done with a rubber lining between the shell and the regular lining, but no definite information as to the value of this inner lining has been reported.

At Flat River (35) liner sections are bolted into place with 1/8-inch shims between the liners and the shell, and then molten zinc is poured between and under the sections so as to form a continuous and cushioned all-metal lining in the mill.

At Homestake (38) rubber lining in pebble mills has given good service and standardizing its use is anticipated, but some cast-iron and Belgian silex linings are still being employed. At Minpro (43) silex is used and at Calumet & Hecla reclamation (6) silex and domestic quartzite comprise the lining material.

At Magma (4) feed-end liners are cast around steel reinforcing bars.

Flat River (35) reports that the liner wear is greatest at the discharge end of the rod mills, but in the Northern Idaho ball mills the feed-end liners wear out first. At Harmony (3) liner wear is reduced by using smaller balls and at Verde Central (14) by slow mill speed.

The amount of liner wear is given in table 2, column 14.

Discharge Openings

The size of the discharge openings varies. Generally, rod mills have larger discharges than ball mills, although the low pulp level of the grate type of ball mill is reputedly the equivalent of a large discharge, since it reduces the amount of the pulp at the discharge

Generated on 2024-09-17 15:00 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

end of the mill and creates a steeper pulp gradient within the mill. At Copper Queen (10) the rod mills (primary) have low-center discharges, whereas the ball mills (secondary), which are of similar design, have high-center discharges. At Nacozari (7) both primary and secondary grinders are rod mills, but they differ in the size of the discharge trunnions; the primary mills have 30-inch and the secondary have 18-inch openings. At both Nacozari (7) and Copper Queen (10) the mills with the larger discharge trunnions require more power; and at Cananea (2) low power is attributed in part to the high pulp level discharge.

Mills with grate discharges are used in at least five concentrators [Magma (4), Engles (16), Walker (17), Alaska Juneau (37), and Questa (44)]. Grate openings are from ¼ inch [Walker (17)] to 1 inch [Alaska Juneau (37)].

Allied with all these operating conditions is the type and amount of feed, which will be considered under "Products."

POWER

The gross horsepower consumption of the grinding mills is presented in table 1, column 17. In a few instances these values had to be estimated. Since the amount of dead load is not obtainable these values include not only the power used to impart action to the balls but also the motor loss and the power necessary to overcome friction in the bearings and drive mechanism. At Cananea (2) low power is attributed in part to roller bearings on the primary rod mills.

Power accounts for as much as 60 percent of the fine-grinding cost [C. & H. congl. (8); Potosi (36)]. Fine grinding is often the largest consumer of power in the entire concentrator, accounting for over half of the total power at 13 plants. See table 1, column 18.

PRODUCTS

Common practice is to feed the mills with the products of the fine crushers, even though this feed may contain material which is already of sufficient fineness. However, in concentrators with flow sheets of types B, E, and F classifiers precede the grinding mills and prepare the feed by removing sands and slimes which need no further grinding. Table 2, column 5, gives skeleton screen analyses of the feeds to the mills. The largest particles in these feeds range from 2½ inches [Alaska Juneau (37)] to 10 mesh [Hayden (1), and Arthur and Magna (13)].

Operating conditions should be regulated to suit the particular feed, and it follows that once these conditions have been established the feed should be as uniform as practical. The report on Harmony (3) calls attention to the desirability of having ball-mill feed uniform in size, and this principle has led to large circulating loads and stage-grinding elsewhere. Two stages have been found more efficient than single stage at United Verde (5), and at Miami (18) three stages are used so that the grinding in each mill is confined to as small a range in reduction as possible. At Harmony (3) the tendency is to do more of the grinding in the fine-crushing department ahead of the ball mills and thereby make the ball-mill feed more uniform.

A steady rate of feed is likewise important to the best operation of a ball mill. Because of this, a surge or storage bin is often placed ahead of the fine-grinding department. At Engels (16) the feed rate to a primary mill is regulated largely by the sound of the mill. At Porcupine (40) the feed is cut off if the discharge becomes too coarse for amalgamation.

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Finished Product

The size to which an ore is ground is determined by the degree of locking of gangue and mineral grains, the succeeding process, or the commercial demands. The finishing size ranges from 96 percent minus 10 mesh [Alaska Juneau (37)] to 96 percent minus 300 mesh [Kirkland Lake, (41)]. Skeleton screen analyses of finished products are shown in table 2, column 6.

Sizing diagrams of the products of several mills are shown in figures 2 to 9, inclusive. These diagrams are made in the manner described by Coghill[7] and show the sizing analyses of (1) the new feed to the mill, (2) the actual feed, which is a weighted composite of the new feed and circulating load, (3) the mill discharge, (4) the circulating load, and (5) the finished product of the grinding circuit. The percentage of material retained on each sieve is plotted bilaterally to give a symmetrical diagram. The minus 200-mesh fractions are shown in dotted lines. Tall diagrams represent coarse products and short diagrams fine products. Wide areas indicate a concentration by weight at a particular size range. The numbers below the diagrams show the relative amounts of each product. The tonnages and other operating data for the circuits which are diagrammed may be found in the tables.

CLASSIFICATION

Fine grinding mills may be closed, or followed, by screens, concentrating machines, or classifiers of the thickener, drag, spiral, or rake type. In the concentrators reviewed, the latter are the more common; there are about 170 reciprocating rake classifiers in the ball- and rod-mill circuits alone. The number, size, and kind of classifiers are given in table 1, column 19.

The size of the overflow and the degree of removal of the fines depend on the amount of material handled, the amount of water in the overflow, washing, slope, and rake speed. When fine overflows (say 100 mesh) are desired, the slope is as flat as 2 inches per foot, and the rake speed is about 12 strokes per minute [Porcupine (40), Kirkland Lake (41), and Questa (44)]; but for overflows containing 35- to 48-mesh material, slopes up to 4 inches per foot and speeds up to 35 strokes per minute are used [Cananea (2), Harmony (3), and Homestake (38)].

An average from 18 concentrators showed that the capacity of a rake classifier may be considered as 2 tons of solids per hour per linear foot of overflow lip.

The efficiency of the classification in several circuits is shown in the diagrams in figures 2 to 9 inclusive. The numbers under "removal, percent" are approximations of the amounts of the various size-increments of the mill discharge which were removed in the finished product. These numbers would be "100" for perfect classification at that size beyond which grinding is no longer necessary. However, the presence of heavy sulphides and locked or middling grains makes the finishing size indeterminable, so that no exact evaluation of the efficiency of the classifiers can be made without study and additional data.

At Cananea (2) and Nacozari (7) back-wash water is used to remove slimes from the classifier, but at Copper Queen (10) this practice was not found to be advantageous to the entire grinding circuit. At Harmony (3) and at Magma (4) water is added to the ball-mill discharge. At Questa (44) an indicating hydrometer is kept in the classifier overflow.

---

7 Coghill, Will H., Evaluating Grinding Efficiency by Graphical Methods: Eng. and Min. Jour., vol. 126, Dec. 15, 1928, pp. 934-8.

Generated on 2024-09-17 14:43 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

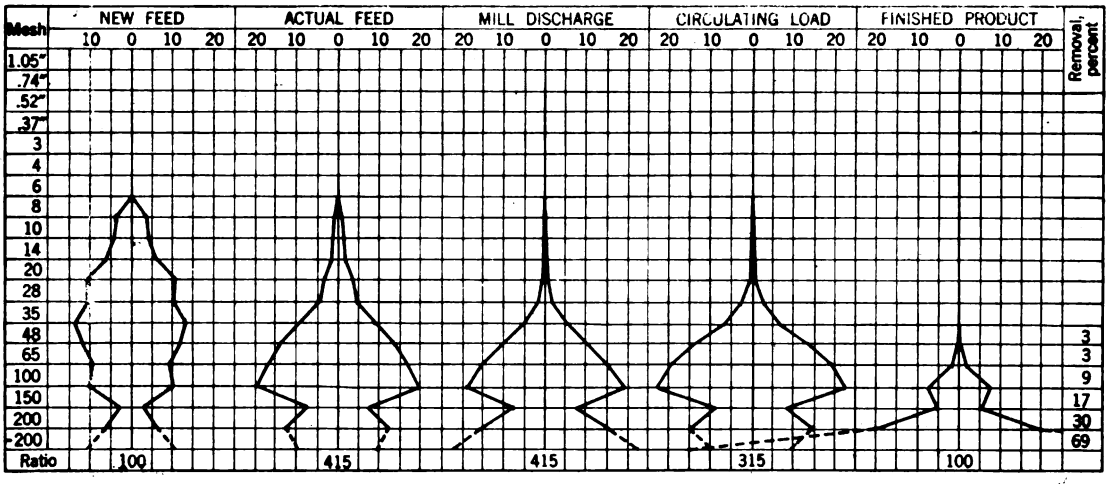


Figure 4.—Sizing diagrams of products of 6-by 12-foot secondary ball mill at Engels (16).

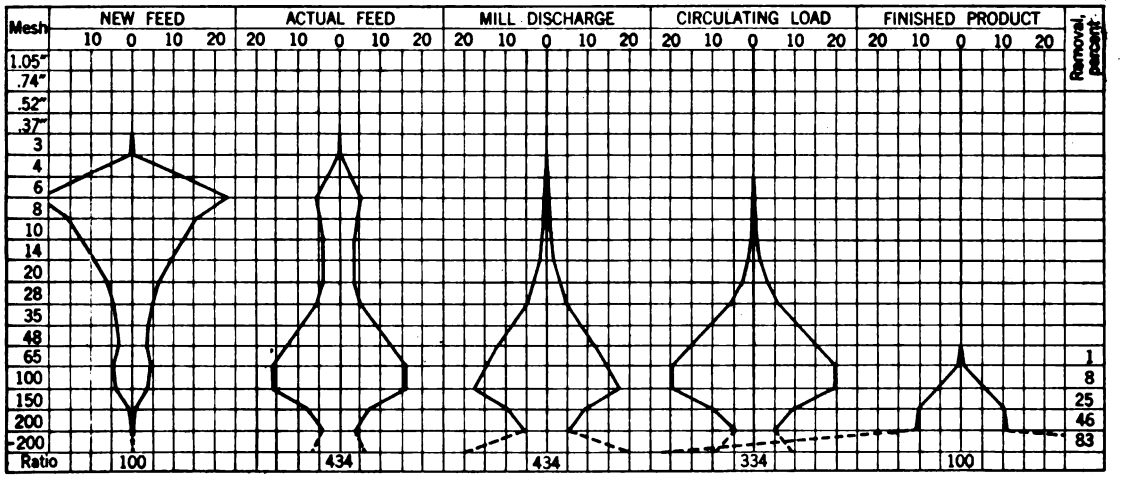


Figure 5.—Sizing diagrams of products of low-grade middling ball mill at West concentrator, northern Idaho (20a).

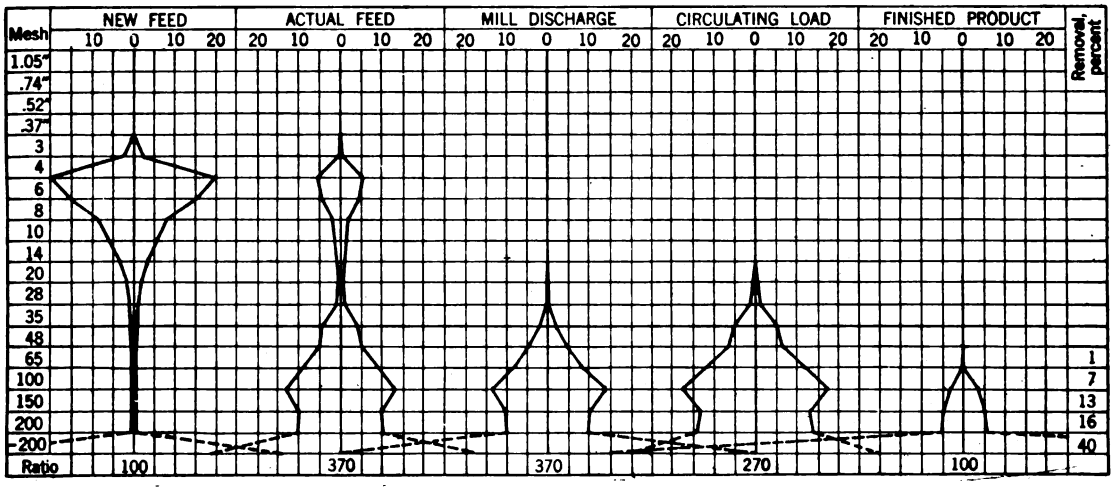


Figure 6.—Sizing diagrams of products of ball mill at Sweeny concentrator, northern Idaho (20b).

Generated on 2024-09-17 14:41 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

REAGENTS

Reagents are added to ball mills as shown in table 2, column 7. Of these, lime is the most common. It is generally added as a conditioning agent for some subsequent treatment, but at Nacozari (7) it serves also to prevent liner wear due to electrolysis.

COSTS

Power for fine grinding is not only the largest item in power consumption in many concentrators, but also, in some instances [Alaska Juneau (37), Minpro (43)] it accounts for half of the total milling cost. In other plants it amounts to 10 to 45 percent of the total. Fine-grinding costs as low as $0.05 per ton have been obtained at Britannia (19) under very favorable conditions. Grinding costs and their distributions, together with the total milling costs, are given in table 2, columns 8 to 12, inclusive. These figures are per ton of ore concentrated, not necessarily per ton of ore ground.

Of the factors contributing to the cost of fine grinding, power is usually the most important. Power generated for 0.2 cent per kilowatt-hour, and locally manufactured balls and liners have made possible the phenomenally low cost mentioned at Britannia (19). The average recorded cost of power is about 1 cent per kilowatt-hour.

Supplies are chiefly balls and liners, and table 2, columns 13 and 14, shows the iron wear in pounds per ton of ore concentrated. When balls or liners are made locally, scrap can be utilized and the wastage from worn liners, broken rods, and rejected balls can be minimized [Cananea (2), Nacozari (7), Morenci (11), Old Dominion (12), Arthur and Magna (13), Britannia (19), Alaska Juneau (37), and Spring Hill (39)].

At Hughesville (27) wear on the lip of the feed scoops has been reduced by applying stellite with an acetylene welding torch.

SUMMARY

A review has been made of the fine-grinding practice in 49 concentrating plants in the United States, Alaska, Canada, Mexico, and Cuba; and the operation of 470 ball, rod, and pebble mills has been set forth. The methods of operation, grinding capacities, and milling costs have been assembled and tabulated to show the present practice and to facilitate comparisons between various mills. Considerable diversity in the details of operation and in the grinding accomplished is apparent; and certain trends in fine-grinding practice, and also the variables of operation have been indicated.

Generated on 2024-09-17 14:44 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

BIBLIOGRAPHY

A list of the milling methods circulars discussed in this review of fine grinding follows:

Reference No.	I. C. No.	Title (reference name underscored)
1	6241	Garms, W. I., Concentrator methods and costs at the Hayden plant of the Nevada Consolidated Copper Co.
2	6261	Tye, A. T., Milling methods and costs at the concentrator of the Cananea Consolidated Copper Co., Cananea, Sonora, Mexico.
3	6285	Gardner, R. Duncan, Milling methods and costs at the Harmony mines, Baker, Idaho.
4	6319	Rose, J. H., and McNabb, J. C., Milling methods and costs at the concentrator of the Magma Copper Co., Superior, Ariz.
5	6343	Kuzell, C. R., and Barker, L. M., Milling methods and costs at the concentrator of the United Verde Copper Co., Clarkdale, Ariz.
6	6357	Benedict, C. Harry, Method and costs of treatment at the Calumet & Hecla reclamation plant.
7	6358	Rose, E. H., and Cramer, W. B., Milling methods and costs at the Nacozari concentrator of the Phelps Dodge Corporation, Sonora, Mexico.
8	6364	Benedict, C. Harry, Milling method and cost at the conglomerate mill of the Calumet & Hecla Consolidated Copper Co.
9	6394	Hodges, Fred, Milling methods at the Hurley plant of the Nevada Consolidated Copper Co., Hurley, N. Mex.
10	6404	Whittenau, E., and Cramer, W. B., Milling methods and costs at the Copper Queen concentrator of the Phelps Dodge Corporation, Bisbee, Ariz.
11	6460	Crowfoot, Arthur, Concentrating methods and costs at the Morenci concentrator of the Phelps Dodge Corporation, Greenlee County, Ariz.
12	6467	Forrester, D. L., and Cramer, W. B., Milling methods and costs at the concentrator of the Old Dominion Co., Globe, Ariz.
13	6479	Martin, H. S., Milling methods and costs at the Arthur and Magna concentrators of the Utah Copper Co.
14	6489	Dickson, R. H., and Smith, E. M., Milling methods and costs at the Verde Central concentrator, Jerome, Ariz.
15	6544	Kirchner, A. R., Galloway, J. V., and Schoder, W. P., Milling methods and costs of the Minas de Matahambre, S. A., concentrator.
16	6550	Nelson, W. I., Milling methods and costs at the Superior concentrator of the Engels Copper Mining Co., Plumas County, Calif.
17	6555	McKenzie, M. R., and Lancaster, H. K., Milling methods at the concentrator of the Walker Mining Co., Walkermine, Calif.
18	6573	Hunt, H. D., Milling methods and costs at the concentrator of the Miami Copper Co., Miami, Ariz.
19	6619	Munro, A. C., and Pearse, H. A., Milling methods and costs at the concentrator of the Britannia Mining & Smelting Co., Ltd., Britannia Beach, B. C.
20	6314	Handy, R. S., Milling methods and costs at the Northern Idaho Mills of the Bunker Hill & Sullivan Mining & Concentrating Co.

Generated on 2024-09-17 14:41 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Reference No	I. C. No.	Title (reference name underscored)
21	6320	Wigton, G. H., Milling methods and costs at the concentrator of the Chief Consolidated Mining Co., Eureka, Utah.
22	6342	Sansom, Frank W., Milling practice at the Netta mine of the Eagle Picher Lead Co., at Picher, Okla.
23	6353	Crabtree, E. J., Jr., Milling practice at the White Bird concentrator, Canam Metals Corporation, Picher, Okla.
24	6359	Wright, Ira L., Milling methods and costs at the Black Hawk concentrator, Hanover, N. Mex.
25	6379	Strachan, C. B., Milling methods of the American Zinc Co. of Tennessee, Mascot, Tenn.
26	6430	Blackburn, W. H., Milling methods and costs at the Lead-Zinc concentrator of the Treadwell Yukon Co., Ltd., at Tybo, Nev.
27	6447	Vanderburg, Wm. O., Milling methods at the Hughesville concentrator of the St. Joseph Lead Co., Hughesville, Mont.
28	6492	Pallanch, R. A., Milling methods at the Midvale concentrator of the U.S. Smelting, Refining, & Mining Co., Midvale, Utah.
29	6497	Andrus, D. E., Milling methods and costs at the Montana mine concentrator of the Eagle-Picher Lead Co., Ruby, Ariz.
30	6574	Knaebel, John B., Milling methods at the Balmat mill of the St. Joseph Lead Co., Balmat, St. Lawrence County, N. Y.
31	6587	Dalton, M. P., Milling methods and costs at the Morning concentrator of the Federal Mining & Smelting Co., Mullan, Idaho.
32	6590	Price, G. S., Milling methods and costs at the Page concentrator of the Federal Mining & Smelting Co., Kellogg, Idaho.
33	6600	Zeigler, W. L., Milling methods and costs at the lead concentrator of the Hecla Mining Co., Gem, Idaho.
34	6605	Bemis, H. D., Milling methods and costs at the Pecos concentrator of the American Metal Co., Tererro, N. Mex.
35	6658	Coghill, Will H., and O'Meara, R. G., Milling methods and costs at a Flat River (Mo.) mill.
36	6706	Mehring, C. A., Bacon, F. G., and Wiser, Oba, Milling methods and costs at the San Guillermo concentrator of the Compania Industrial "El Potosi," S. A., San Guillermo, Chihuahua, Mexico.
37	6236	Bradley, P. R., Milling practice at the Alaska Juneau concentrator.
38	6408	Clark, Allan J., Milling methods and costs at the Homestake mine, Lead, S. Dak.
39	6411	Grant, L. A., Milling methods and costs at the Spring Hill concentrator of the Montana Mines Corporation, Helena, Mont.
40	6433	Vary, Ronald A., Amalgamation practice at Porcupine United Gold Mines, Ltd. Timmins, Ontario.
41	6508	Dixon, John, Milling practice of the Kirkland Lake Gold Mines, Ltd., Kirkland Lake, Ontario.
42	6541	Reddington, John, Milling methods and costs of the Coniaurum Mines, Ltd., Schumacher, Ontario.
43	6488	Burgess, B. C., Methods and costs of milling feldspar at the Minpro plant, Tennessee Mineral Products Corporation, Spruce Pine, N.C.
44	6551	Carman, J. B., Milling methods and costs at the Questa concentrator of the Molybdenum Corporation of America, Questa, N. Mex.

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

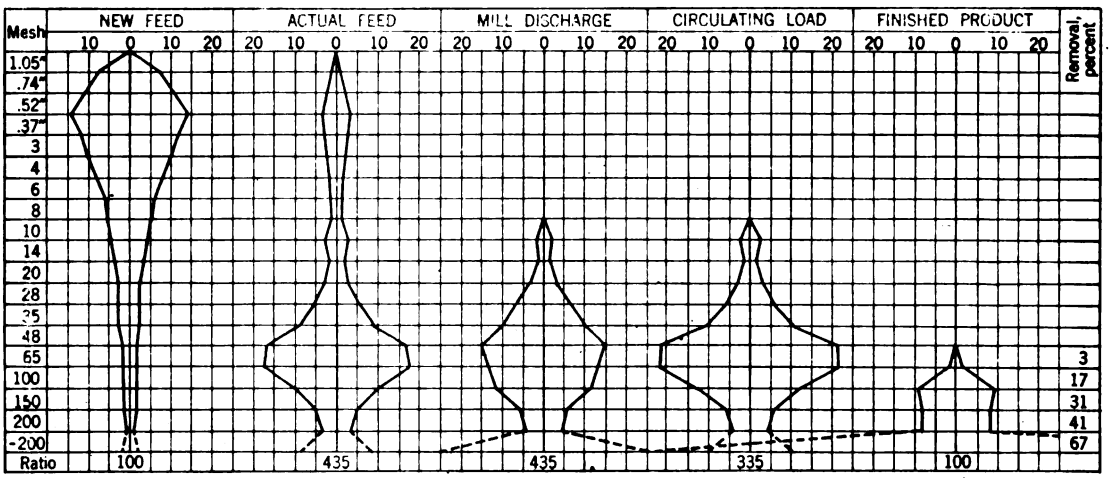


Figure 7.– Sizing diagrams of products of ball mill at Chief Consolidated (21).

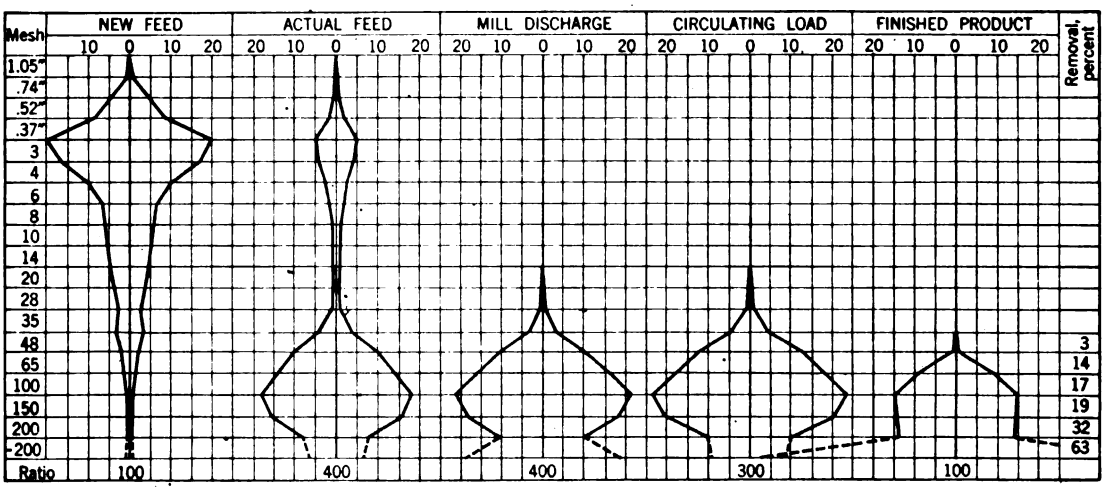


Figure 8.– Sizing diagrams of products of rod mill at Hughesville (27).

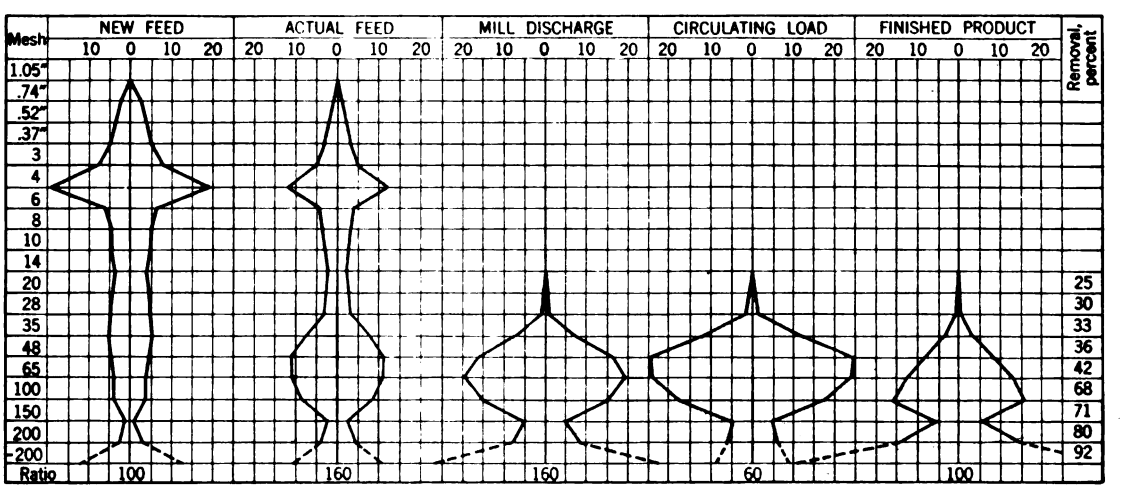


Figure 9.– Sizing diagrams of products of primary rod mill at Midvale (28).

Generated on 2024-09-17 14:40 GMT / https://hdl.handle.net/2027/osu.32435030644116
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY